Equitable Transportation and Resilience Hubs: Analysis of Underserved Population Needs, Usage, and Travel

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Thayanne G. M. Ciriaco[a, b]
Graduate Student Researcher
thayanne@ualberta.ca
(Corresponding Author)

Syeda Narmeen Zehra[a, b]
Graduate Student Researcher

Veronica Wambura[a, b]
Graduate Student Researcher

Dr. Stephen D. Wong[a, b]
Assistant Professor

[a] Department of Civil and Environmental Engineering, University of Alberta, Edmonton, AB, Canada

[b] Resilient and Sustainable Mobility and Evacuation Group, University of Alberta, Edmonton, AB, Canada

UNIVERSITY OF ALBERTA

RESUME Group
RESILIENT AND SUSTAINABLE MOBILITY & EVACUATION GROUP

ABSTRACT

Extreme weather events and other hazardous events often require a range of strategies to safely shelter people, distribute resources, and start recovery efforts. This is particularly important for underserved populations who often lack reliable access to shelters, transportation, and social networks. To begin addressing these problems and increase community capacity, resilience hubs – physical locations that support residents in emergencies and everyday conditions – have emerged as a possible equitable strategy. Despite potential benefits for underserved populations, research and practice have yet to consider how different demographic groups will use or travel to/from these hubs.

To address these gaps, we conducted an empirical study using survey data from 950 respondents in the Edmonton Metropolitan Region in Alberta, Canada, and particularly focused on several underserved groups. Simple descriptive statistics and statistical tests were used to understand the groups' needs and observe similarities and divergences between groups. Additionally, we used spatial analysis to identify whether there was a relationship between resilience hub locations proposed by respondents and the transportation mode they would use to get there. We found that respondents prioritized basic services such as water, food, and restrooms during normal conditions and emergency scenarios. Moreover, our mode choice analysis highlighted the necessity of incorporating multimodal transportation options to increase accessibility to resilience hubs. Finally, we found that to achieve equitable results, resilience hubs should be placed in locations with the greatest need. Based on these results, we offer several policy recommendations that directly inform the equitable development of resilience hubs.

Keywords: Resilience Hubs, Community Resilience, Equity, Accessibility, Disaster Preparedness

1) INTRODUCTION

Extreme weather events caused by climate change and non-climate-related emergencies continue to devastate many cities around the world (*1*). In response, researchers, practitioners, and policymakers are calling for a new paradigm in planning, one that involves mitigation, adaptability, and recovery from change, also known as resilience planning. To better protect, serve, and help residents during emergencies, jurisdictions are building or considering resilience hubs. These hubs are community-serving physical spaces that support residents, coordinate communication and services, and provide resource distribution before, during, or after disasters (*2*). Hubs are intended to provide either temporary or short-term emergency shelter during an evacuation. They are also designed to serve community members year-round through different programs (e.g., recreation, education, social, etc.). In a comprehensive review of the current literature, (*3*) concluded that the placement and services offered by resilience hubs were key features to consider in their design, implementation, and operation. As noted by current literature (*3–6*), resilience hubs have the potential to promote the well-being of communities and enhance social capital. However, there is no empirical evidence on how underserved populations might use or travel to/from resilience hubs. This is especially problematic as current resilience hub design may not align with community needs or assist underserved populations. We asked three questions to begin addressing this gap:

1) What services do underserved populations prefer in a resilience hub?
2) How will underserved populations access resilience hubs?
3) How do underserved populations and non-underserved populations differ in hub usage?

To answer these research questions, we surveyed 950 respondents from the Edmonton Metropolitan Region in Alberta, Canada between September 2022 and January 2023. Focused on resilience hubs, the dataset contains information on the type of services that different demographic groups prioritize, both during everyday conditions and for a disaster. Using these data, we conducted a simple statistical analysis and a spatial analysis to highlight differences in resilience hub usage and group accessibility. Results inform several key recommendations for resilience hub placement and transportation operations that can specifically benefit underserved populations. The methods are also relatively simple to reproduce, enabling other jurisdictions or community-based organizations (CBOs) to conduct similar analyses.

This paper is organized as follows. First, we present a brief literature review about resilience hubs and equity challenges that arise during evacuations. Following that, we explain the data collection and the methodology. Then, we present the results and discussions. Finally, we conclude the paper with policy recommendations and overall conclusions.

2) LITERATURE REVIEW

We organized our literature review by general area of interest: 1) evacuations and equity challenges, 2) resilience hub design, and 3) literature gaps.

2.1) Evacuations and Equity Challenges

The impacts of climate change and non-climate-related disasters have been consistently shown to disproportionately affect underserved populations (*7–9*). Low-income households, racial and ethnic minority groups, people with disabilities, older adults, women, and children are highly vulnerable to both the environmental and health consequences of climate change (*8*). These populations often lack access to reliable transportation which can be a major barrier to evacuating in times of disaster. For example, private and public vehicles are often not equipped to accommodate specialized mobility or medical equipment which may be crucial for the evacuation of people with disabilities or older adults. Moreover, low-income residents often choose not to evacuate due to the cost, as was the case during Hurricane Katrina in New Orleans (*10*). Through an Evacuation Preparedness Rating System, (*11*) found that only 26% of the evacuation plans from the 50 largest cities of the United States presented strategies on how to assist underserved and transportation-disadvantaged populations during a disaster. Moreover, a study

conducted in New Orleans found that while the city had established pick-up points for transit users, many of these were not strategically located close to those with the greatest need (the elderly, low-income households, and people with disabilities) (*12*).

Evacuation shelters often serve as the first temporary living spaces for evacuees during and after a disaster. While there is substantial research on the types of shelters people choose during an emergency (*13*), many of these shelters remain unequipped to accommodate the needs of underserved populations. During Hurricane Katrina, for example, many Red Cross shelters were unable to accommodate people with disabilities (*7*). Moreover, those who were elderly or physically frail had difficulties accessing the shelters due to long waiting lines (*14*). Previous studies have shown that social and physical barriers in shelters can limit these populations' compliance with evacuation orders (*15*). As such, agencies and jurisdictions are responsible for ensuring that shelters meet the specific needs and challenges faced by different underserved groups.

Ensuring an equitable provision of both transportation and shelter resources along with sufficient community cohesion and social capital are also important in disasters. In a study of the 1995 Chicago heat wave, (*16*) found that isolated elderly individuals with few social ties were less likely to be rescued and more likely to die. (*17*) further found that when residents of communities have high trust and compassion for others, they are more likely to share resources in a disaster. A bottom-up mechanism for social cohesion within neighborhoods could create equitable communities where the needs of underserved populations are known and met (*18*). It is within this framework that resilience hubs can play an essential role.

2.2) Resilience Hub Design

Resilience hubs, as community-based locations, play a crucial role in providing essential services and resources during times of crisis (*4*). These hubs can operate in three different modes: 1) everyday/normal conditions, 2) response or disruption mode, and 3) recovery mode (*3, 19, 20*), and their elements depend on community needs. To maximize their effectiveness, these hubs should be well-established and trusted within the community and equipped with extensive support and coordination capabilities (*19*). For example, hubs can be placed in recreation centers, libraries, community halls, government buildings, schools, or large buildings (e.g., stadiums, conference centers, etc.). Recent research has begun to highlight the role of resilience hubs in promoting social cohesion, along with significant gaps in transportation considerations (*3*). The success of hubs likely depends on their ability to address community needs, diverse staffing, clear communication, and community involvement in emergency planning (*21*).

Strategies adopted during the planning phase of a resilience hub should consider the projections of increased frequency and intensity of extreme weather events due to climate change (*22*). As noted in a report by (*21*), developing and maintaining community relationships can lead to a deeper understanding of community dynamics and help uncover hidden vulnerabilities. For example, Vibrant Hawai'i, a community-based leadership organization observed that communities in the County of Hawai'i were facing challenges during the COVID-19 pandemic and created resilience hubs to assist these communities. Hub services assisted 41,733 households by facilitating access to a computer and Wi-Fi connectivity for distance learning for children, providing prepared meals and food boxes, and training people for jobs (*23*). These hubs remain operational, adapting physical spaces to the dynamic needs of the community (*24*).

Multiple factors affect the selection of a resilience hub by community members. For instance, research has found that the perceived importance of emergency shelters by potential end users depends on factors such as safety, hygiene, proximity to friends and family, privacy, provisions of special meals, and access to the Internet (*25*). Another study noted that individuals with access and functional needs (AFN) must

also be considered and integrated in disaster and emergency management planning (*26*). Consequently, the location of a resilience hub and its associated transportation characteristics play a key role in improving access for underserved populations during disasters and normal days.

2.3) Key Literature Gaps

The current literature has developed a strong understanding of resilience hub's concept, characteristics, and functionalities. Literature has also identified significant challenges for underserved populations, especially related to transportation. In this context of equity, transportation, and resilience hubs, three key literature gaps exist. First, studies are currently lacking in an equity assessment or empirical evidence on how underserved populations will use resilience hubs. Second, research has only peripherally addressed how resilience hubs should be located based on community preferences and needs. Finally, there is no evidence on how underserved populations will travel to/from these hubs. The goal of this study is to begin addressing these existing gaps and to obtain insight into the placement of and the type of services that can be offered by resilience hubs to meet the needs of diverse demographic groups. Using Edmonton, Canada as a case study, we aim to inform policy and decision-making regarding the functionality and design of resilience hubs more broadly, especially for mid-sized, North American cities. The methodology presented in this paper is intended to be simple to use for broader case study development across diverse cultures, geographies, and places.

3) DATA COLLECTION

To focus on individual behavior and needs, we collected survey data via the Qualtrics platform through a market research panel and a convenience sample. The market research panel sampling, also known as an online sample, is when participants are recruited from a pre-arranged group of people subscribed to a platform to participate in surveys (*27*). Panel recruitment was conducted by Qualtrics. Convenience sampling, also known as accidental sampling or opportunity sampling, is a non-probability sampling technique that does not require a random selection of participants (*28*). For convenience recruitment, the survey link was disseminated through social media, newsletters, and emails from organizations and agencies such as community leagues, the City of Edmonton, and the Edmonton Food Bank.

We collected data for the Edmonton Metropolitan Region (with a population of about 1.3 million people) from September 2022 to January 2023. Data cleaning was conducted to remove uncompleted responses, extremely fast responses, highly patterned responses, and participants who could not be verified of living inside the Edmonton Metropolitan Region. The final sample consisted of 950 observations. The survey questionnaire was designed to determine the respondents' socioeconomic and demographic profile (e.g., age, gender, education, income, household composition, and number of vehicles in the household) and to investigate their evacuation plans, preparedness for emergencies, risk perceptions, and opinions about resilience hubs. In addition to the survey data collected, we identified open-access socioeconomic and demographic data and shapefiles (e.g., Edmonton boundary, neighborhood boundaries, recreation center, libraries) from the City of Edmonton Census, the Province of Alberta Census, and the Canada Census to create thematic maps (*29–31*).

4) METHODS

The flowchart below (**Figure 1**) shows the methodological process that was followed in this study. The methodology is designed to be modular, allowing for the selection of different analyses for replication by other communities using local survey data.

To assess the underserved groups' characteristics and needs, the final sample was subdivided into seven groups based on socioeconomic and demographic characteristics, including people with disabilities, older adults (65 years and over), women, households with children, carless, low-income households (household income under $50,000 CAD), and visible minorities. According to the Employment Equity Act, visible minorities are "persons, other than Aboriginal peoples, who are non-Caucasian in race or non-white in

color". We note that not *all* members of each of the groups are necessarily underserved. Moreover, there are other populations that not included in this analysis (e.g., non-English speakers, houseless, recent immigrants). However, we chose these groups because: 1) they or their household traditionally experience increased vulnerability in disasters and 2) there was sufficient data to analyze them as a group. As a note, we use the term "underserved" rather than "vulnerable" to denote systematic barriers, though this wording may change in the future.

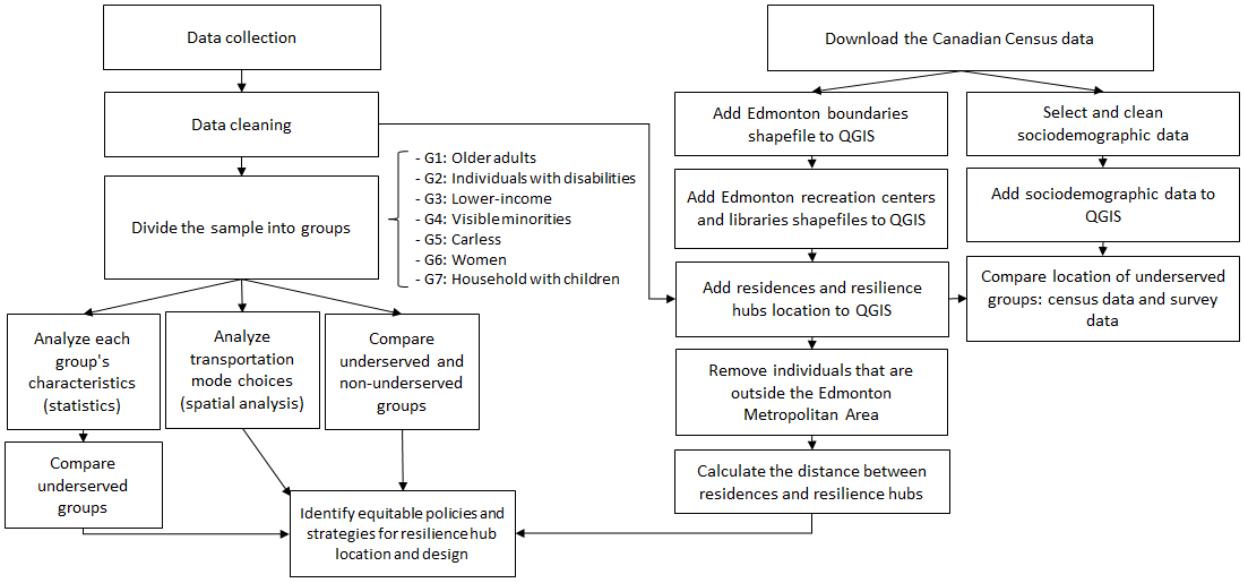

Figure 1 Flowchart of the methodology

Through simple statistical examination, we explored how the behavior of each underserved group is related to their use of resilience hubs in disaster and normal situations and how it connects to services identified by them as essential. Moreover, we conducted a comparative analysis between underserved and non-underserved groups using cross tabulations and Pearson chi-square tests to identify different usage of resilience hubs. We also employed simple spatial analysis to examine Euclidean distance from a location proposed by respondents to allocate hubs and their residences, with a segmentation of mode choice. Future work can extend these methods by leveraging spatial optimization, discrete choice analysis, accessibility analyses, and machine learning.

5) RESULTS

The demographics in the survey data (n = 950) produced a good (but not ideal) general population sample for the Edmonton Metropolitan Region. The average age of respondents was 38, which aligns with the 2021 Canadian Census which found an average age of 38.8 among residents of the Edmonton Metropolitan Area (*30*). However, only 4% of the respondents in our sample made up the older adults group (>=65 years). More than half of the respondents in our survey identified as women (54.5%), 43.2% as men, and other genders (e.g., non-binary, two-spirit, transgender) comprised 1.9% of the respondents. The majority of the respondents in our survey were white (54.5%) and 28.3% were visible minorities, a relatively high sample. With regard to car ownership, only 4.9% did not have an automobile whereas the rest of the respondents had at least one automobile in their households. In our survey, 22.7% had an income under $50,000, 43.3% had an income between 50,000 and $100,000, and 29.1% had an income of $100,000 and over, and. Moreover, 71.8% of the survey respondents had completed a diploma, bachelor's, graduate or professional degree, or doctorate. Finally, 35.4% of the respondents reported having a disability.

5.1) Resilience Hub Characteristics based on Underserved Groups

This section provides an overview of key resilience hub characteristics selected by underserved groups in our survey. **Table 1** presents a summary of each underserved group's preference of resilience hub location, basic and emergency services, transportation mode to/from a resilience hub. **Table 2** presents an overview of each underserved group's resilience hub usage.

TABLE 1 - Resilience hub characteristics by underserved group

Underserved Groups		**Visible minorities**	**People with disabilities**	**Low-income households**	**Carless Residents**	**Women**	**Households with children**	**Older adults**
Places where a resilience hub could be located (top five locations) **(*Very and somewhat satisfied*)**		Community center (77.6%)	Community center (78.5%)	School (68.8%)	Community center (78.7%)	Community center (75.1%)	Community center (76.1%)	School (84.6%)
		School (75.1%)	School (73.7%)	Community center (66.1%)	University (72.3%)	School (74.6%)	School (74.3%)	Community league[1] (79.5%)
		University (71.9%)	University (70.3%)	Library (62.4%)	Library (72.3%)	University (68.6%)	University (69.1%)	Religious building (79.5%)
		Library (68.7%)	Library (66.8%)	University (61.8%)	Community league (68.1%)	Library (68.5%)	Library (66.7%)	Community center (76.9%)
		Government building (66.9%)	Community league (66.0%)	Shopping mall (61.3%)	Governmen t building (68.1%)	Community league (67.7%)	Community league (64.9%)	Shopping mall (74.4%)
		Visible minorities	**People with disabilities**	**Low-income households**	**Carless Residents**	**Women**	**Households with children**	**Older adults**
Transportation services and resources at resilience hubs **(*Very and mostly important)***	Accessible for individuals with disabilities	65.5%	76.7%	69.4%	76.6%	71.9%	68.2%	82.1%
	Bike parking	28.5%	22.8%	34.4%	27.7%	28.1%	34.0%	20.5%
	Bike sharing	29.5%	25.4%	35.5%	27.7%	28.1%	34.6%	20.5%
	Car parking	54.4%	58.2%	54.8%	44.7%	60.6%	58.1%	46.2%
	Heated bus stop	42.7%	41.0%	40.3%	38.3%	39.2%	45.4%	28.2%
	Parking for electric vehicles	39.9%	35.3%	36.6%	31.9%	37.1%	39.7%	25.6%
	Resilience hub be within walking distance from residence	49.8%	52.6%	57.5%	57.5%	53.9%	52.9%	66.7%
	Transit connection	54.1%	56.0%	54.8%	61.7%	57.2%	59.4%	56.4%

[1] Community leagues are neighborhood-based, non-profit organizations created under the Societies Act of Alberta, Canada, to meet community needs (Hairsine, 2015).

		Visible minorities	People with disabilities	Low-income households	Carless Residents	Women	Households with children	Older adults
Emergency services and resources from resilience hubs ***(Very and mostly important)***	Community emergency response training	60.9%	66.4%	66.7%	57.5%	65.8%	66.9%	64.3%
	Back-up/emergency power	71.2%	79.3%	71.0%	76.6%	77.2%	75.9%	92.9%
	Shelter (temporary in disaster)	71.2%	80.2%	77.4%	74.5%	81.6%	78.5%	89.3%
	Support for reuniting families	66.9%	72.4%	69.9%	68.1%	73.4%	74.1%	78.6%
	Information desk	65.8%	73.3%	67.7%	68.1%	70.6%	71.1%	82.1%
		Visible minorities	**People with disabilities**	**Low-income households**	**Carless Residents**	**Women**	**Households with children**	**Older adults**
Basic services and resources from resilience hubs ***(Very and mostly important)***	Water	79.7%	85.8%	79.6%	78.7%	87.8%	86.6%	89.3%
	Food bank	74.0%	79.7%	77.4%	74.5%	82.4%	79.2%	82.1%
	Warming center	77.2%	84.1%	78.5%	78.7%	84.5%	82.5%	85.7%
	Cooling center	62.3%	68.1%	65.1%	61.7%	65.4%	64.7%	67.9%
	Wi-Fi	55.2%	50.9%	59.7%	68.1%	58.9%	59.0%	53.6%
	Restrooms	77.9%	38.4%	77.4%	51.1%	43.4%	82.2%	96.4%
	Showers	65.1%	84.9%	70.4%	85.1%	84.9%	69.7%	71.4%
	Basic health services	74.0%	82.8%	74.7%	78.7%	78.4%	74.8%	92.9%
	Market/ grocery	58.4%	65.1%	64.5%	72.3%	64.2%	63.4%	60.7%
	Urgent care	67.3%	77.2%	74.2%	72.3%	73.8%	68.2%	82.1%

Based on the survey responses (see **Table 1**), several potential locations were identified for resilience hubs. Among the underserved groups surveyed, the most suggested places were community centers, schools, universities, libraries, government buildings, community leagues and shopping malls. In particular, community centers received very/somewhat satisfaction ratings from 66.1% to 78.7% of participants, while schools, universities, and libraries were favored by 61.8% to 84.6% of respondents.

Regarding transportation services offered by resilience hubs, a majority of older adults (82.1%) and people with disabilities (76.7%) indicated that it is very/mostly important that resilience hubs offer transportation accessibility features. A high number of older adults (66.7%) further indicated that it was very/mostly important for resilience hubs to be located within walking distance from residences. On the other hand, carless residents placed the highest importance on transit connections (61.7%), followed by households with children (59.4%). Services related to personal vehicles were more favored by women than other underserved groups. For instance, 60.6% of the women indicated that car parking was a very/mostly important resilience hub service compared to 44.7% of the carless population and 46.2% of

the older adults. Interestingly, all the survey respondents had low inclinations for selecting micromobility services such as bike sharing and bike parking as important for resilience hubs. Low-income households accounted for the highest number of respondents who selected both bike sharing and bike parking services as very/mostly important (35.5% and 34.4% respectively).

Survey respondents also indicated emergency services they regarded as very/mostly important to be offered by resilience hubs. Back-up and emergency power were selected by most of the underserved groups as important, with responses ranging from 71.0% (low-income households) to 92.9% (older adults). Many respondents also noted that offering temporary shelters during emergencies was an important feature, with strong prioritization from older adults and women (89.3% and 81.6% respectively). Surprisingly, respondents were less inclined to select community emergency response training as one of the critical services to be provided by resilience hubs (between 57.5% to 66.9% stating very/mostly important).

Apart from transportation and emergency services, respondents further indicated other basic services they perceived as important to be offered at resilience hub locations. Many of the participants selected both water and food banks as critical. Many of the older adults (82.1%) also indicated that it was important that resilience hubs offer urgent care services. Other services such as showers and warming centers during the winter also garnered high interest (65.1% to 85.1% and 77.2% to 85.7% respectively). Wi-Fi connections were a lower priority, with a very/mostly important range of 50.9% (people with disabilities) to 68.1% (carless residents).

5.2) Intended Resilience Hub Usage

The underserved groups' likelihood to use a resilience hub varied under different circumstances (**Table 2**). For example, during normal conditions, only 31.6% of the older adults indicated that they were very/somewhat likely to use a resilience hub. On the other hand, during emergency conditions, 76.9% of the older adults' group were very/somewhat likely to use resilience hubs as temporary evacuation shelters (see **Table 2**). This trend was similar for the other underserved groups. While only 34.1% of the carless residents would use a resilience hub during normal conditions, 70.2% would use it during an emergency scenario as a temporary evacuation shelter and 74.5% would use it as a place to gather information about the disaster.

Table 2. Resilience Hub Usage by Underserved Groups

Underserved Groups		**Visible minorities**	**People with disabilities**	**Low-income households**	**Carless Residents**	**Women**	**Households with children**	**Older adults**
Likelihood to use a resilience hub ***(Very likely and somewhat likely)***	Under normal conditions	44.2%	40.5%	51.1%	34.1%	40.7%	45.4%	31.6%
	As a temporary evacuation shelter	66.5%	69.8%	6f2.9%	70.2%	64.1%	64.3%	76.9%
	As a place to gather critical resources during a disaster	63.0%	71.6%	67.2%	68.1%	67.9%	66.7%	74.4%
	As a place to meet with neighbors during a disaster	43.4%	38.4%	34.9%	34.0%	39.0%	43.4%	53.8%
	As a place to gather information about the disaster	73.0%	74.1%	66.7%	74.5%	72.8%	73.5%	84.6%

		Visible minorities	People with disabilities	Low-income households	Carless Residents	Women	Households with children	Older adults
Volunteer at the resilience hub *(Very likely and somewhat likely)*	During normal days	47.0%	41.8%	47.3%	57.5%	44.4%	48.5%	48.7%
	During relief efforts	61.9%	62.9%	64.0%	36.2%	62.7%	61.2%	82.0%
		Visible minorities	**People with disabilities**	**Low-income households**	**Carless Residents**	**Women**	**Households with children**	**Older adults**
A resilience hub would help *(Yes)*	Increase social cohesion in my neighborhood	62.6%	61.6%	54.3%	59.6%	58.7%	61.2%	71.6%
	Meet the needs of neighbors on a daily basis	55.9%	56.0%	52.7%	55.3%	55.8%	58.8%	48.7%
	Community to be more resilient	66.5%	66.0%	65.0%	63.8%	65.6%	65.6%	69.2%

Furthermore, the underserved groups showed varying levels of likelihood to volunteer at a resilience hub. During normal days, carless residents accounted for the largest percentage of those who would volunteer at a resilience hub (57.5%) whereas women comprised the lowest (44.4%). During relief efforts, however, the likelihood of volunteering significantly decreased among carless individuals to 36.2%. On the other hand, the rest of the underserved groups showed higher likelihoods to volunteer during relief efforts with older adults at the highest level (82.0% very/somewhat likely).

For hub benefits, a high number of older adults (71.6%) indicated that resilience hubs would foster increased social cohesion in their neighborhoods, though only 54.3% of the low-income households agreed with this statement. Moreover, 58.8% of households with children believed that resilience hubs would effectively meet the needs of neighbors, compared to 48.7% of the older adults. Conversely, many of the older adults believed that resilience hubs would cause their communities to be more resilient (69.2%) compared to 63.8% of the carless residents. Despite these subtle differences, nearly all groups across all three questions (**Table 2**) answered positively to resilience hub benefits, indicating strong potential to meet community needs.

5.3) Comparison of Underserved and Non-Underserved Groups Resilience Hub Usage

We next employed cross tabulation analysis and conducted Pearson chi-square tests to determine usage difference between underserved and non-underserved groups. Here, we define non-underserved as all people who are not in the underserved group (not considering intersectionality). For example, we compare visible minorities with non-visible minorities. The cross tabulation breaks down the data based on two categorical variables, displaying the frequencies in each pair. Then, the Pearson chi-square test identifies correlation between categorical variables. The null hypothesis (H0) posits that there is no association between the classification of individuals and their usage of resilience hubs, while the alternative hypothesis suggests that such an association exists. If the p-value is found to be less than 0.05, we reject the null hypothesis, indicating that there is a relationship between classification of individuals and their usage of resilience hubs, as tested. It is worth noting that none of the crosstab cells had an expected count of less than 5, ensuring that the assumptions for chi-square testing were satisfied. **Table 3** presents the p-values from the Pearson chi-squared test.

TABLE 3 P-values of the Person Chi-Squared Test of underserved groups with resilience hub usage (binary categorization)

	Visible minority	People with disability	Low-income	Carless	Women	Household with children	Older adult
Feel comfortable to use a resilience hub as a shelter during a disaster	0.669	0.285	0.996	0.889	0.857	0.229	0.035*
Would volunteer at a resilience hub during relief effort	0.521	0.330	0.242	0.691	0.081	0.556	0.004*
Would volunteer at a resilience hub during normal days	0.343	0.357	0.376	0.243	0.966	0.016*	0.581
Would use resilience hub during normal days	0.238	0.762	0.003*	0.296	0.657	0.015*	0.298
Would use resilience hub during a disaster as a temporary shelter	0.031*	0.002*	0.586	0.191	0.043*	0.060	0.039*
Would use resilience hub during a disaster as a place to gather critical resources	0.667	0.005*	0.295	0.540	0.005*	0.087	0.165
Would use resilience hub during a disaster as a place to meet neighbors	0.104	0.663	0.150	0.426	0.689	0.020*	0.063
Would use resilience hub during a disaster as a place to gather information during a disaster	0.183	0.097	0.301	0.474	0.023*	0.018*	0.039*
Would use resilience hub during a disaster as a place to volunteer	0.125	0.351	0.937	0.244	0.905	0.001*	0.016*

* 95% significance
H0: there is no association between the variables (independent)
H1: there is an association between the variables (dependent)

Table 3 uncovers notable correlations between underserved and non-underserved groups and their utilization of resilience hubs. For example, with regard to volunteering at a resilience hub during relief efforts, only the older adults group showed statistical significance in relation to their binary counterpart (non-older adult). Combined with Figure 2 which shows the percentage of intended usage, this result suggests that older adults are more likely to volunteer at resilience hubs during relief efforts than non-older adults. Regarding the use of resilience hubs as temporary shelters during disasters, the results indicate a statistically significant relationship between the following underserved groups and the non-underserved counterparts: older adults, women, people with disabilities, and visible minorities. Figure 2 demonstrates that this is a positive relationship. For using resilience hubs to gather information, significant associations were also observed between the following underserved groups and the respective non-underserved counterparts: women, households with children, and older adults. As Figure 3 indicates, these underserved groups displayed higher levels of willingness to use resilience hubs to gather information compared to their counterparts. We further noted that across the various underserved groups, there was generally a higher willingness to use resilience hubs as places to gather information about disasters. This was observed among all the groups except the lower-income households (**Figure 3**).

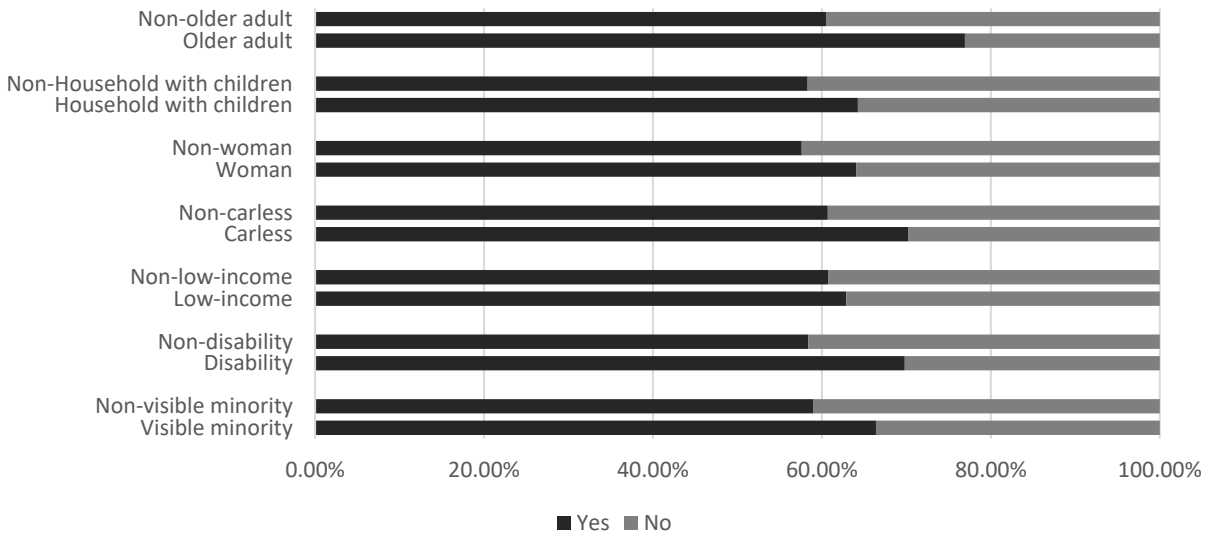

Figure 2 Usage of resilience hub as a temporary shelter during a disaster

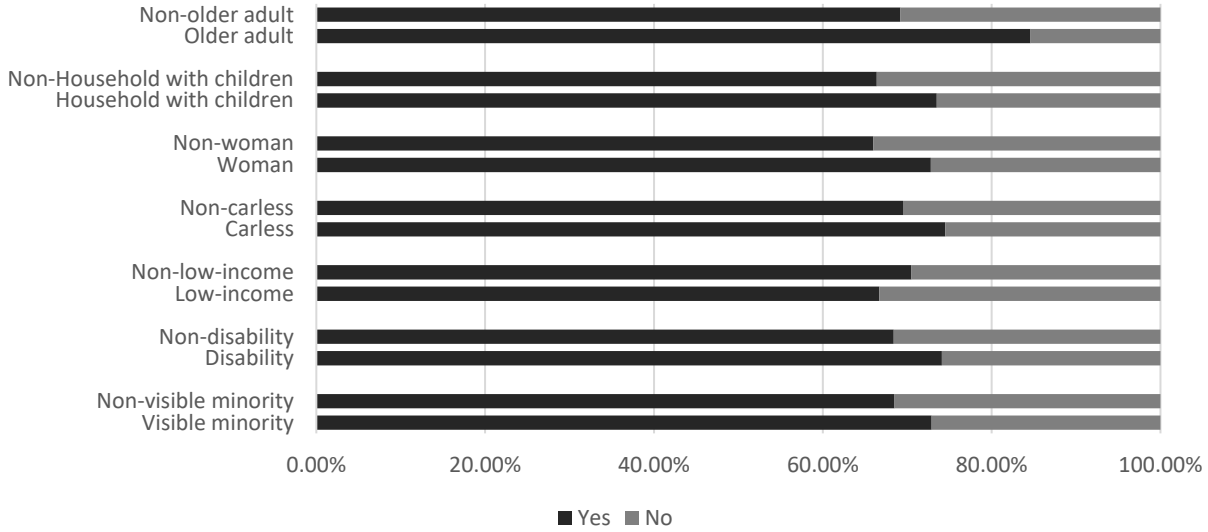

Figure 3 Would use a resilience hub as a place to gather information during a disaster

5.4) Resilience Hub Accessibility by Underserved Group

We summarized the stated preference of mode choice selection during normal conditions and emergencies by the survey respondents in Table 4. Additionally, we calculated the Euclidean distance between participants' residences and the place that they chose as a potential location for a resilience hub. To understand the results better for each group, we used median distance as a measure of central tendency instead of average distance, which is more sensitive to extreme values.

TABLE 4 - Mode choice during normal condition and emergency condition by underserved group

	Visible minorities	**People with disabilities**	**Low-Income households**	**Carless residents**	**Women**	**Households with children**	**Older adults**
Distance (median in km) between resilience hub and residence	**2.2**	**1.5**	**1.7**	**2.4**	**1.5**	**1.7**	**1.6**
Sample size	*240*	*184*	*146*	*40*	*428*	*377*	*28*
Median distance between residence and resilience hub by mode (km)							
Personal vehicle	**2.7** *N = 160*	**1.5** *N=123*	**1.4** *N=92*	**5.7** *N=9*	**1.7** *N=286*	**2.1** *N = 252*	**1.1** *N=15*
Public Transit (Bus, rail, micro-transit)	**3.1** *N = 19*	**2.5** *N=18*	**2.8** *N=12*	**2.7** *N=11*	**2.3** *N=26*	**1.6** *N = 30*	-
Walk	**0.6** *N = 26*	**0.7** *N=26*	**0.7** *N=22*	**0.7** *N=15*	**0.6** *N=75*	**0.6** *N = 44*	0.4 *N=13*
Shared mobility (Carpooling, Ridesourcing, Carsharing, rental car)	**1.9** *N = 12*	**3.2** *N=7*	**2.3** *N=6*	**4.4** *N=6*	**1.8** *N=10*	**1.5** *N = 20*	-
Other	-	-	**14.4** *N=2*	-	**1.3** *N=1*	**5.2** *N = 2*	-
Mode Choice - Normal condition							
Personal vehicle	72.2%	66.8%	71.2%	20.5%	71.1%	72.0%	51.6%
Public Transit (Bus, rail, micro-transit)	9.4%	10.9%	7.7%	27.3%	7.1%	9.2%	0.0%
Walk	11.4%	16.1%	15.3%	38.6%	17.9%	11.4%	44.7%
Shared mobility (Carpooling, Ridesourcing, Carsharing, rental car)	6.9%	6.2%	4.7 %	13.6%	3.8%	6.8%	2.6%
Other	0.0%	0.0%	1.2%	0.0%	0.2%	0.5%	0.0%
Sample size	*245*	*211*	*170*	*44*	*476*	*411*	*38*
Mode Choice - Emergency condition							
Personal vehicle	82.2%	75.5%	73.8 %	16.0%	81.1%	79.5%	78.6%
Public Transit (Bus, rail, micro-transit)	2.7%	6.4%	5.6 %	16.0%	4.0%	3.5%	0.0%
Walk	8.9%	11.8%	11.2%	48.0%	7.3%	5.7%	17.9%
Shared mobility (Carpooling, Ridesourcing, Carsharing, rental car)	4.8%	2.7%	9.4 %	12.0%	5.2%	8.7%	3.6 %
Other	1.4%	3.6%	0.0%	8.0%	2.4%	2.6%	0.0%
Sample size	*146*	*110*	*107*	*25*	*248*	*229*	*28*

By examining the distance between resilience hubs and respondents' residences, we found that individuals from all underserved groups tended to select close-by places, with the median distance range being 1.5 to 2.4 km. While analyzing the distance by mode of transportation, those who selected walking as a preferred mode to reach the resilience hub selected locations even closer to their residences (0.4 to 0.7 km) as a potential resilience hub location. This preference was consistent across all underserved groups. For individuals relying on personal vehicles, carless individuals were willing to travel 5.7 km, while older adults indicated a willingness to travel 1.1 km. All other groups fell within the range of 1.4 to 2.7 km. The visible minorities group presented the highest median distance for public transit trips (3.1 km), whereas all other groups, except older adults, selected locations that were between 1.6 and 2.8 km away.

During normal conditions, using a personal vehicle was the first preferred mode choice for all underserved groups, except carless individuals. About 72% of the individuals belonging to visible minorities, low-income households, women, and households with children would use personal vehicles to reach the resilience hub. Conversely, only 20.5% of carless individuals would use personal vehicles. Moreover, walking emerged as a popular mode amongst older adults (44.7%) after personal vehicles (51.6%). Furthermore, it is the first option for the carless group (38.6%), and the second option for all other groups. This suggests that these groups would benefit if resilience hubs were closer to their residences. Carless residents indicated being more likely to use public transit to reach resilience hubs during normal conditions. However, public transit would meet other underserved groups' mobility needs as it would be used by a range of 7.1% to 10.9% of the individuals.

During an emergency, personal vehicles remained the most popular mode choice for all groups except carless individuals. Walking emerged as the primary choice for carless individuals (48.0%), and as the second most chosen mode for all other groups, except households with children who preferred shared mobility. The preference for shared mobility over walking among households with children during emergencies is likely due to the availability of more accessible and flexible transportation options for evacuating children. In comparison to other underserved groups, carless residents accounted for the highest percentage of those who would use public transit to access resilience hubs during an emergency. Noting differences in the mode choice under normal and disruptive conditions, the use of transit decreased among all the underserved groups during an emergency.

6) POLICY RECOMMENDATIONS

Based on the survey results and our analysis, we offer several key recommendations to assist in developing and implementing resilience hubs. We organize these recommendations based on 1) resilience hub services, 2) resilience hub locations, and 3) access to resilience hubs.

6.1) Resilience Hub Services

During an emergency scenario, three main services were prioritized by all underserved groups within our study: temporary shelters during disasters, backup power, and support for reuniting families. As noted by (*32*), hazard risks vary across locations and population groups. Therefore, we recommend that jurisdictions perform risk assessments to develop an understanding of temporary shelter requirements and emergency resources considering current and future hazards in their particular locations. We further recommend that on-site backup power be integrated into resilience hubs, particularly for those requiring ventilators, suctioning machines, and refrigeration for food and medicine. Moreover, similar to *(3)*, we recommend that resilience hubs should have family reunification plans to ensure that family members and children are connected to their families following an emergency.

During normal conditions, basic services such as water, food banks, and showers were highly prioritized by underserved populations. Providing these basic needs at resilience hubs has been shown to promote equity and resilience in jurisdictions such as Hawai'i, San Francisco, and Detroit (*23*, *33*, *34*). We recommend that resilience hubs connect with food banks and integrate the growth of local foods to cater to the residents' basic needs. The provision and maintenance of showers and restrooms are also essential to the operation of resilience hubs both during normal conditions and during disasters.

6.2) Resilience Hub Locations

Regarding locations, our survey data showed that a majority of the vulnerable group respondents live in central Edmonton, with many of them having residences close light rail access (known as LRT) (**Figure 4**). While the process of prioritizing locations will differ with each jurisdiction, previous literature has shown that resilience hubs should be established in already well-utilized locations (*3*, *19*). As such, we recommend that jurisdictions select locations that are well-known by the community and especially the underserved groups in order to promote usage during normal conditions and emergency scenarios. In

addition, existing locations such as community centers, libraries, schools and universities, and shopping malls could be retrofitted to serve as resilience hubs. This will ensure a cost-effective approach to creating resilience hubs while leveraging locations that are already well-established and familiar to the surrounding communities. Finally, within our study, low-income populations and older adults were willing to travel the shortest distances to reach resilience hubs. Jurisdictions should therefore prioritize building resilience hubs in close proximity to particularly underserved groups in order to equitably meet the needs of all community members.

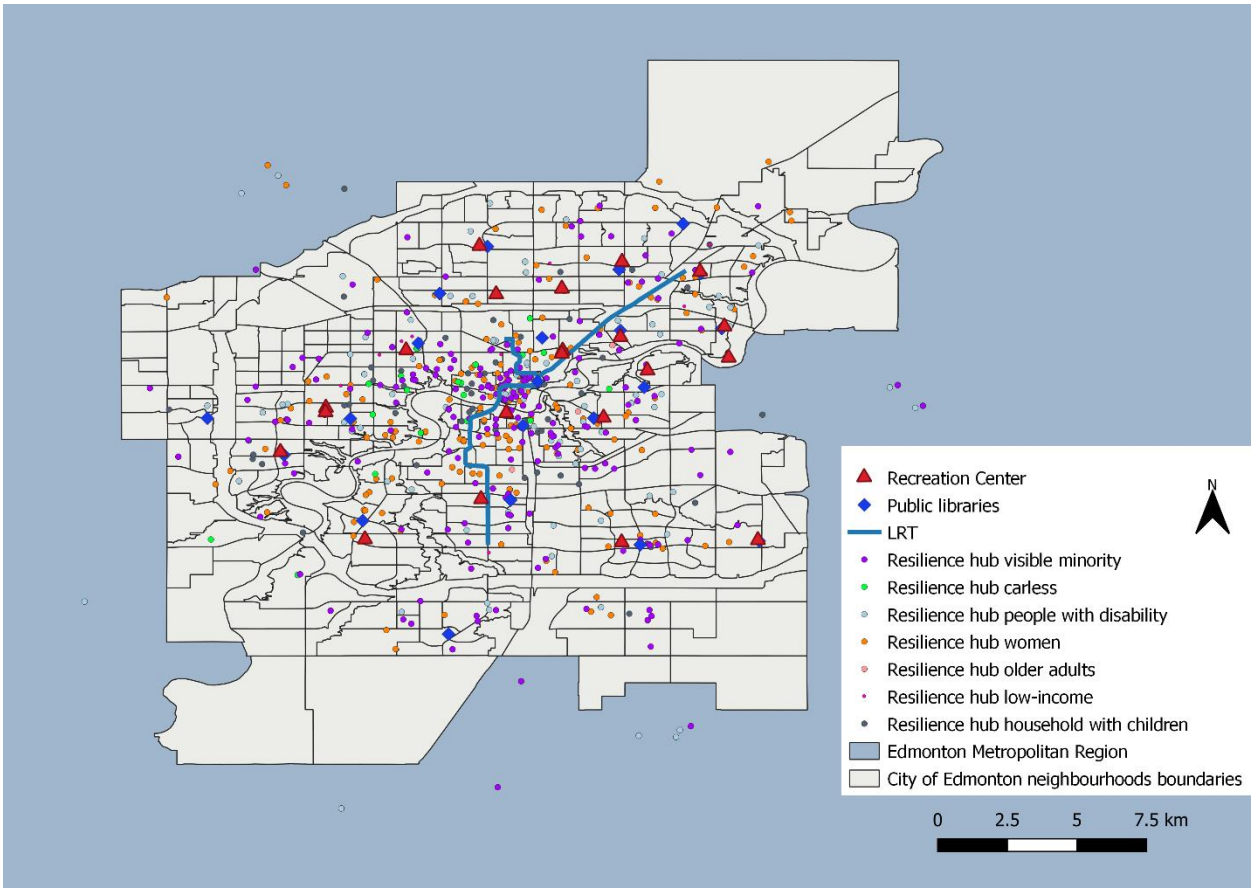

Figure 4 - Resilience hubs' potential locations

6.3) Transportation and Access

In the design and selection of resilience hubs, accessibility and connectivity play crucial roles. Integrating transportation systems such as bus routes, rail lines, and other public transportation options is essential to ensure easy and safe travel between hubs and residences (*35*). Our results also indicate that public transit is still a likely option in both normal and emergency conditions, especially for certain underserved groups. We recommend that jurisdictions integrate transportation systems with both resilience hub planning and evacuation planning to ensure safe and reliable travel during emergencies.

Particularly within our study, underserved groups prioritized individual accessibility features, transit connections, and close walking distances to resilience hubs. As such, we recommend that resilience hub designs feature ramps, lifts, and other assistive technologies for people with disabilities, older adults, and others with limited mobility. To further enhance travel access and address the diverse needs and abilities of individuals, the incorporation of multimodal transportation options is crucial (*36*). Public transit systems, encompassing buses, trains, and light rail, serve as efficient and accessible modes of

transportation, particularly for those without private vehicles. Communities should consider integrating multiple transportation options into resilience hub planning as this further contributes to improved resilience and redundancy in the system (*36*). This will ensure that, in the event of disruptions or inaccessibility of one mode of transportation, other modes can continue operating to/from hubs.

Finally, previous research has shown that multimodal transportation options play a vital role in addressing social equity issues (*37*). This is because they offer accessible and affordable transportation choices, regardless of individuals' socioeconomic background (*38*). Jurisdictions should ensure that underserved communities, who may have limited access to private vehicles, can reach resilience hubs during normal conditions and emergencies and receive the necessary support and resources. For long-term benefits, co-planning and co-locating transit centers, mobility hubs, and affordable housing with resilience hubs could lead to important sustainability, resilience, and equity benefits.

7) LIMITATIONS

Despite the important insights obtained in this study, several limitations should be noted. First, because the survey utilized an online format, individuals without reliable internet access and those with limited digital literacy may have been excluded from participation. To reduce this issue, we collaborated with community leagues, the Edmonton Food Bank, and the City of Edmonton for survey distribution. Second, the convenience data collection may have self-selection bias since people opted into the survey Furthermore, some underserved groups (i.e., older adults, carless residents) were underrepresented (compared to Census data) in the study, which could affect the generalizability of results.

We also recognize limitations in the spatial analysis methodology employed in this study. First, the distance between the respondents' selected resilience hub location and their residence was calculated based on Euclidean distance which may not accurately reflect travel distance or travel time. Additionally, some participants were excluded from the analysis since they: 1) did not select a location for either their residence or the resilience hub; or 2) selected hub locations that were outside the Edmonton Metropolitan Region. Finally, we acknowledge that a spatial optimization of the respondents' residences was not conducted when identifying potential resilience hub locations. Future studies should consider optimizing resilience hub locations based on community-led criteria and the spatial distribution of underserved groups. This spatial understanding could be further coupled with discrete choice analysis models that better predict the underserved groups' behavior and mode choices in relation to resilience hubs.

8) CONCLUSION

This study contributes to the understanding of resilience hubs and their role in promoting community resilience during emergency situations and normal conditions. By investigating in the needs and behavior of underserved groups, including low-income households, older adults, households with children, visible minorities, people with disabilities, and carless individuals, we identified key characteristics that these groups seek in a resilience hub. Our findings provide valuable insights into the design and implementation of resilience hubs to effectively meet the diverse socio-demographic needs.

Based on our results, we recommend that resilience hubs prioritize essential services such as the availability of water, restrooms, foodbanks, and accessibility for people with disabilities. Additionally, these hubs should serve as temporary refuges during disasters. Furthermore, we found a correlation between the proposed location of resilience hubs and respondent's residence. Our mode choice analysis highlights the unique needs of each group during normal conditions and an emergency. Altogether, the research points to a clear need to integrate transportation with resilience hub design and placement. This includes both site-specific and network-level changes to make resilience hubs operational and useful for those who need them most. Ultimately, our research has identified that empirical evidence, provided directly from underserved populations, can help shape resilience hubs that equitably meet community needs during both normal and disaster conditions.

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AUTHOR CONTRIBUTIONS
The authors confirm contribution to the paper as follows: study conception and design: T. Ciriaco, S. Zehra, V. Wambura, S. Wong; data collection: T. Ciriaco, S. Wong; analysis and interpretation of results: all authors; draft manuscript preparation: all authors. All authors reviewed the results and approved the final version of the manuscript.

REFERENCES

1. USCGRP. *Climate Science Special Report*. Global Change Research Program, Washington, DC, 2017, pp. 1–470.
2. Baja, K. Climate Resiliency: A Unique Multi-Hazard Mitigation Approach. *Journal of Business Continuity & Emergency Planning*, Vol. 9, No. 4, 2016, pp. 304–316.
3. Ciriaco, T. G. M., and S. D. Wong. Review of Resilience Hubs and Associated Transportation Needs. *Transportation Research Interdisciplinary Perspectives*, Vol. 16, 2022, p. 100697. https://doi.org/10.1016/j.trip.2022.100697.
4. Baja, K. RESILIENCE HUBS Shifting Power to Communities and Increasing Community Capacity. USDN, , 2018.
5. Kirwan, D., G. Faber, P. Porter, and T. McCarty. *A FRAMEWORK FOR IMPLEMENTING RESILIENCE HUBS IN YPSILANTI, MICHIGAN*. SEAS - School for Environment and Sustainability - University of Michigan, 2021, p. 84.
6. Sandoval, S. Resilience Hubs in Austin, Texas: Developing Equitable Climate Infrastructure. 2019, p. 48.
7. Benevolenza, M. A., and L. DeRigne. The Impact of Climate Change and Natural Disasters on Vulnerable Populations: A Systematic Review of Literature. *Journal of Human Behavior in the Social Environment*, Vol. 29, No. 2, 2018, pp. 266–281. https://doi.org/10.1080/10911359.2018.1527739.
8. Levy, B. S., and J. A. Patz. Climate Change, Human Rights, and Social Justice. Vol. 81, No. 3, 2015, p. 310. https://doi.org/10.1016/j.aogh.2015.08.008.
9. van Wesenbeeck, C. F. A., B. G. J. S. Sonneveld, and R. L. Voortman. Localization and Characterization of Populations Vulnerable to Climate Change: Two Case Studies in Sub-Saharan Africa. *Applied Geography*, Vol. 66, 2016, pp. 81–91. https://doi.org/10.1016/j.apgeog.2015.11.001.
10. Litman, T. Lessons From Katrina and Rita: What Major Disasters Can Teach Transportation Planners. *Journal of transportation engineering*, Vol. 132, No. 1, 2006, pp. 11–18.
11. Renne, J. L., and E. Mayorga. What Has America Learned Since Hurricane Katrina? Evaluating Evacuation Plans for Carless and Vulnerable Populations in 50 Large Cities Across the United States. Presented at the Transportation Research Board 97th Annual MeetingTransportation Research Board, 2018.
12. Bian, R., and C. G. Wilmot. An Analysis on Transit Pick-up Points for Vulnerable People during Hurricane Evacuation: A Case Study of New Orleans. *International Journal of Disaster Risk Reduction*, Vol. 31, 2018, pp. 1143–1151. https://doi.org/10.1016/j.ijdrr.2017.07.005.
13. Lindell, M. K., J. E. Kang, and C. S. Prater. The Logistics of Household Hurricane Evacuation. *Natural Hazards*, Vol. 58, No. 3, 2011, pp. 1093–1109. https://doi.org/10.1007/s11069-011-9715-x.
14. Saunders, J. M. Vulnerable Populations in an American Red Cross Shelter After Hurricane Katrina. *Perspectives in Psychiatric Care*, Vol. 43, No. 1, 2007, pp. 30–37. https://doi.org/10.1111/j.1744-6163.2007.00103.x.
15. Karaye, I. M., C. Thompson, M. Perez-Patron, N. Taylor, and J. A. Horney. Estimating Evacuation Shelter Deficits in the Houston–Galveston Metropolitan Area. *Risk Analysis*, Vol. 40, No. 5, 2020, pp. 1079–1091. https://doi.org/10.1111/risa.13448.
16. Klinenberg, E. *Heat Wave: A Social Autopsy of Disaster in Chicago*. University of Chicago Press, Chicago, IL, 2015.
17. Wong, S. D., J. L. Walker, and S. A. Shaheen. Trust and Compassion in Willingness to Share Mobility and Sheltering Resources in Evacuations: A Case Study of the 2017 and 2018 California Wildfires. *International Journal of Disaster Risk Reduction*, 2020, p. 101900. https://doi.org/10.1016/j.ijdrr.2020.101900.
18. Idziorek, K., C. Chen, and D. B. Abramson. *Attitudes and Trust in Leveraging Integrated Sociotechnical Systems for Enhancing Community Adaptive Capacity: Phase IV*. 2021.
19. Baja, K. GUIDE TO DEVELOPING RESILIENCE HUBS. USDN, , 2019.

20. Resilience Hub Community Committee. *WARD 7 RESILIENCE HUB PROPOSAL*. 2020.
21. FEMA. A Whole Community Approach to Emergency Management: Principles, Themes, and Pathways for Action. , 2011.
22. Temmer, J., and H. Venema. *Building a Climate-Resilient City: Transportation Infrastructure*. 2019, p. 10.
23. Vibrant Hawaii. 2020 HUBS FINAL REPORT. https://www.vibranthawaii.org/_files/ugd/fb5ef8_832bf02d4e61442aa0a80a34d9ef1e01.pdf. Accessed Mar. 22, 2022.
24. Vibrant Hawai'i. *RESILIENCE HUB MID-YEAR REPORT*. 2022.
25. Asgary, A., and N. Azimi. Choice of Emergency Shelter: Valuing Key Attributes of Emergency Shelters. *International Journal of Disaster Resilience in the Built Environment*, Vol. 10, No. 2/3, 2019, pp. 130–150. https://doi.org/10.1108/IJDRBE-10-2018-0044.
26. Lou, Z. *RESILIENCE BEFORE DISASTER*. 2020, p. 49.
27. Qualtrics. Online Research Panels & Samples for Surveys. *Qualtrics*. https://www.qualtrics.com/research-services/online-sample/. Accessed Feb. 6, 2023.
28. Henry, G. T. *Practical Sampling*. Newbury Park: Sage Publication, 1990.
29. Government of Canada, S. C. Census Geography: Spatial Information Products. https://www12.statcan.gc.ca/census-recensement/2021/geo/sip-pis/index-eng.cfm. Accessed Jun. 4, 2022.
30. Statistics Canada. Census Profile. 2021 Census of Population. https://www12.statcan.gc.ca/census-recensement/2021/dp-pd/prof/index.cfm?Lang=E. Accessed Jun. 22, 2023.
31. Edmonton - Open Data Portal. *Edmonton's Open Data Portal*. https://data.edmonton.ca/browse?q=income&sortBy=relevance. Accessed Jun. 4, 2022.
32. Mardis, M. A., F. R. Jones, E. E. Ozguven, M. Horner, E. Piekalkiewicz, S. Pickett, J. Mathias, and J. D. Leon. Rural Resiliency Hubs: An Integrated, Community-Centered Approach to Addressing the Resiliency Divide through Rural Public Libraries. 2021.
33. Neighborhood Empowerment Network. Empowered Communities Program. *empowersf.org*. https://www.empowersf.org/ecp-communities/. Accessed Mar. 23, 2022.
34. Sands, D. Climate Resilience Hubs Finding a Foothold on Detroit's East Side, Helping Residents Face Disasters. *Metromode*. https://www.secondwavemedia.com/metromode/features/ClimateResiliencyHubs.aspx. Accessed Mar. 23, 2022.
35. Trivedi, A. A Multi-Criteria Decision Approach Based on DEMATEL to Assess Determinants of Shelter Site Selection in Disaster Response. *International Journal of Disaster Risk Reduction*, Vol. 31, 2018, pp. 722–728. https://doi.org/10.1016/j.ijdrr.2018.07.019.
36. Zhou, Y., J. Wang, and H. Yang. Resilience of Transportation Systems: Concepts and Comprehensive Review. *IEEE Transactions on Intelligent Transportation Systems*, Vol. 20, No. 12, 2019, pp. 4262–4276. https://doi.org/10.1109/TITS.2018.2883766.
37. Wang, S., X. Wu, and Y. Chen. Association between Perceived Transportation Disadvantages and Opportunity Inaccessibility: A Social Equity Study. *Transportation Research Part D: Transport and Environment*, Vol. 101, 2021, p. 103119. https://doi.org/10.1016/j.trd.2021.103119.
38. Carpentieri, G., C. Guida, and H. E. Masoumi. Multimodal Accessibility to Primary Health Services for the Elderly: A Case Study of Naples, Italy. *Sustainability*, Vol. 12, No. 3, 2020, p. 781. https://doi.org/10.3390/su12030781.